Mississippi River Climate Change: Status, Challenges and Adaptations

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Key Takeaways

- Climate change is causing significant degradation to the Mississippi River ecosystem.
- Increased water and sediment delivery are making maintenance of the navigation channel difficult and diminishing the quality and quantity of critical backwater habitat.
- Adaptation to these changing conditions requires optimizing connection between channels and backwater habitat, creating deep water refugia in backwaters, planning for increased navigation channel dredging, and making strategic infrastructure retrofits.
- Many successful adaptations have been implemented on the Mississippi River, but more are needed to keep pace with the rate of ecosystem degradation resulting from climate change.

Introduction

Climate change predictions of warmer temperatures coupled with increased precipitation have manifested on the river. Over the past decade, the negative consequences of climate change to Mississippi River health have become very evident. Destruction of island habitat, breaches of natural levees, loss of floodplain forest, changes in water exchange rates between the main channel and backwater lakes and even mudslides have occurred in recent decades (Figure 1-6). While significant degradation to the ecosystem has occurred, floodplain rivers are capable of healing themselves if adaptive measures are implemented to restore the ecosystem.

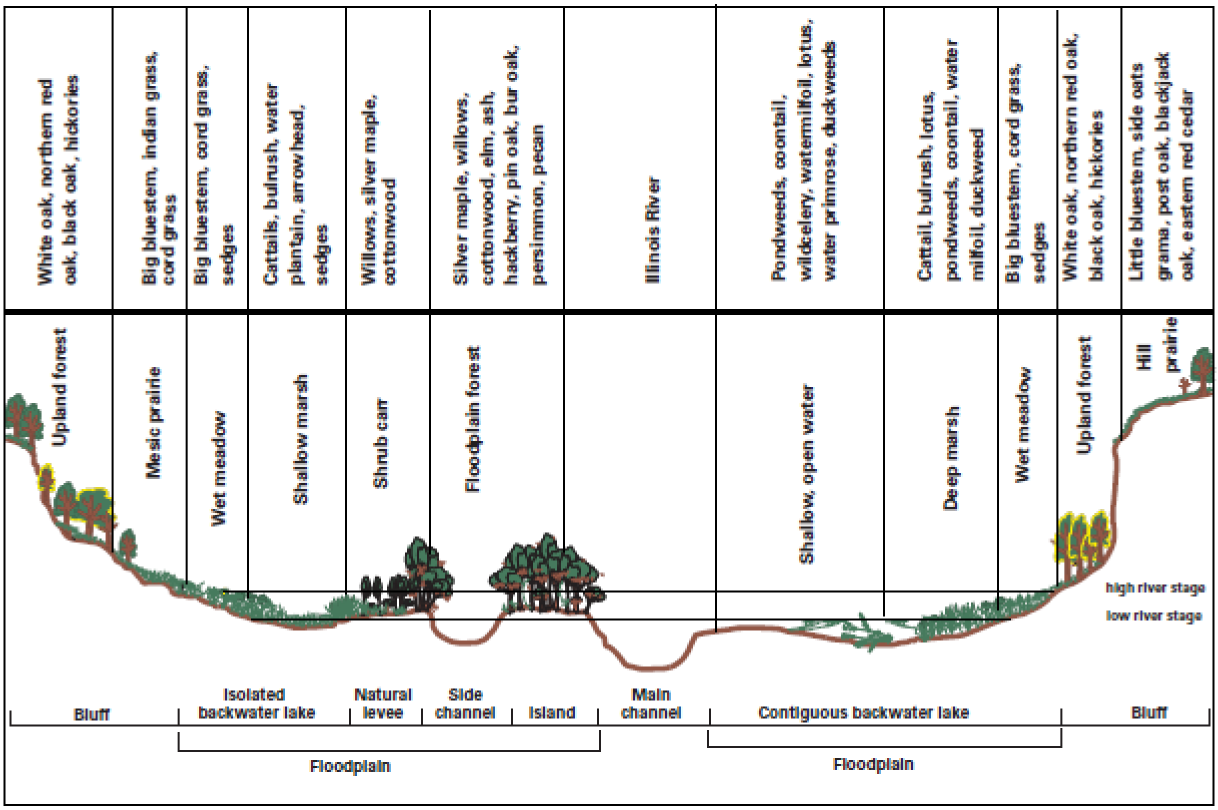


Figure 1. A stylized view of natural floodplain features of the Upper Mississippi River. Image provided by C. Theiling, USACE. (Original sources in References: Nelson, et al. & U.S. Geological Survey, 1999.)

Figure 2. Mississippi River island exhibiting significant erosion as a result of increasing river discharge. Note the forest loss that is occurring as trees are about to fall into the river due to bank erosion.

Figure 3. Natural levee breach on Mississippi River island as result of increasing river discharge and stage that has occurred over recent decades.

Figure 4. The loss of floodplain forest is a symptom of climate change. Extended periods of high river stage result in forest loss.

Figure 5. Mudslide to Mississippi River and consequent property loss. Fifteen inches of rainfall over a 24-hour period triggered the slide.

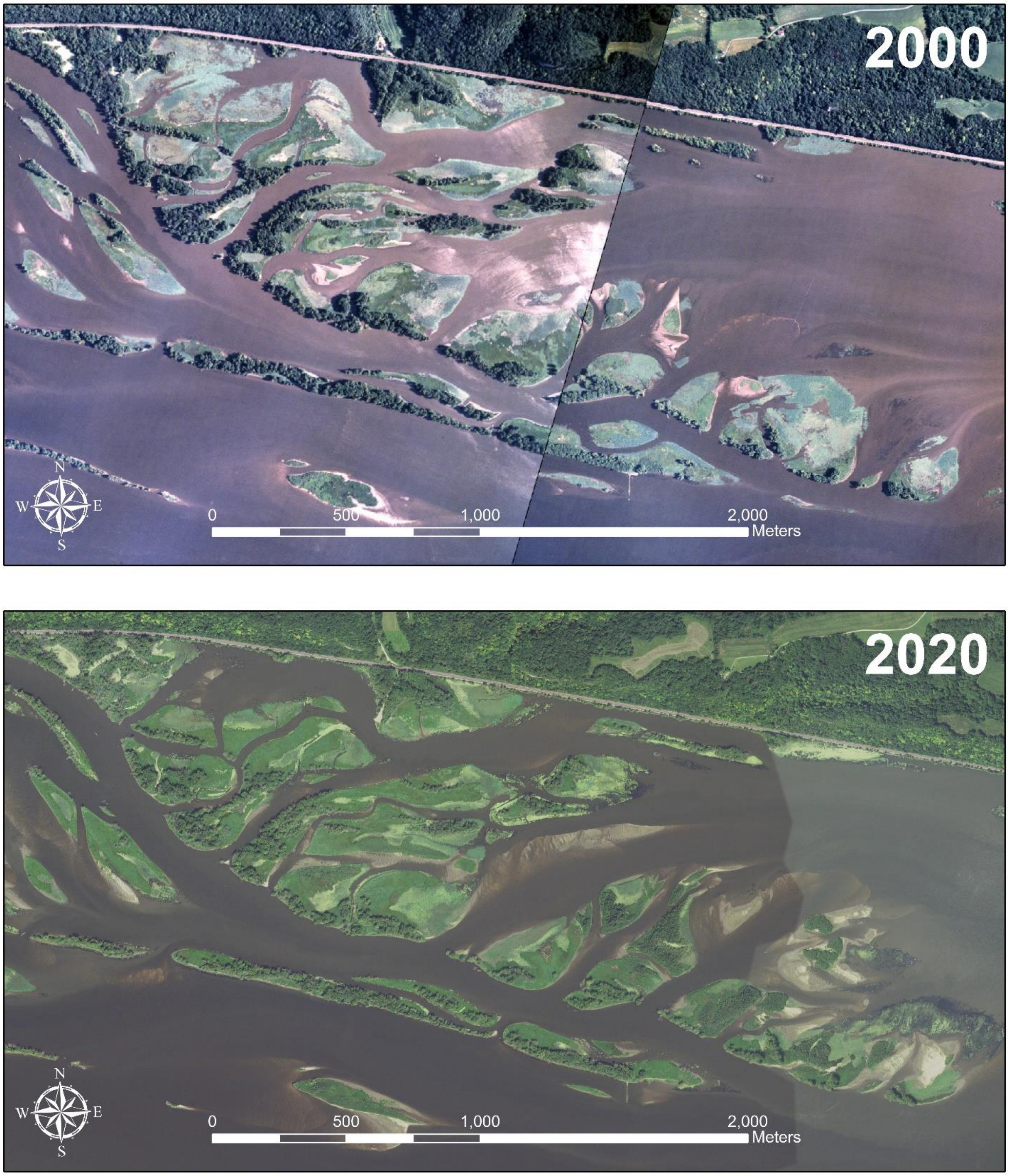


Figure 6. Snyder Slough in Pool 11 in 2000 and 2020. Consequences of climate change such as off-channel sedimentation, loss of aquatic area and forest loss are evident over the twenty-year period. Image: Jeff Janvrin, WI DNR.

Increasing Discharge and Sediment Delivery

One of the most obvious climate change trends is increasing river discharge and river stage. The Mississippi River has a reliable long-term record of discharge. United States Geological Survey (USGS) stream gauge data document the changes that have occurred in discharge. Mean annual discharge never exceeded 45,000 cubic feet per second (CFS) from 1929 to 1980 at the Winona, MN gauge (Pool 6 of the Mississippi River; Figure 7). Conversely, the river exceeded the 45,000 CFS mark 11 times since 1980 with 6 of those year occurring since 2011. This sizable change is upsetting the balance of the ecosystem. In an open, uncontrolled river, habitats and channels would respond to increasing flows by adjusting banks, channels, bedforms and floodplain features to adapt to a new energy regime. This channel evolution process harnesses physical processes to reform the river system. Due to the impoundment caused by navigation dams and the floodplain constriction caused by levees, railroads and roadbeds, the managed Upper Mississippi River System cannot reform these habitats entirely unassisted.

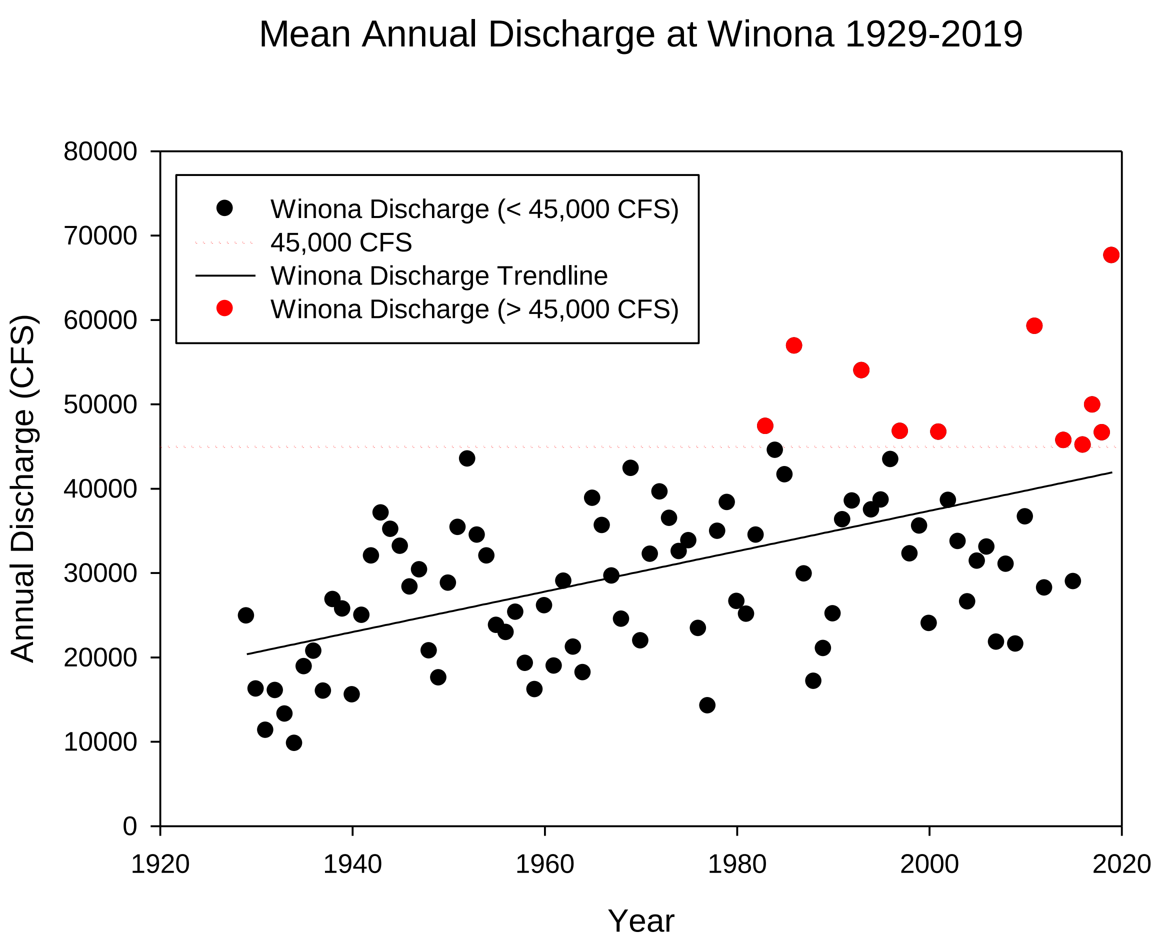


Figure 7. Mean annual discharge at Winona, MN 1929-1980. United States Geological Survey stream gauge data. CFS = cubic feet per second.

Dredging has been increasing in recent years in the St. Paul District of the U.S. Army Corps of Engineers, which covers 9 of the 10 navigation pools that border Wisconsin. In the early 1980s, reductions in dredging depths were instituted to reduce the amount of material generated by maintenance dredging while keeping the channel open with a reasonable margin of safety to avoid rapid shoaling. With the current trend toward increased annual discharge, more material is mobilized into the main channel, leading to higher dredging requirements and more widespread dredging need (Figure 8). What once was a system of manageable dredge cuts in known locations with a relatively predictable recurrence frequency may become a system where imminent threats of channel closure (i.e. impassable conditions for commercial navigation) may arise at multiple locations simultaneously. This creates operational challenges that are coupled with long-standing hindrances to getting rid of the dredged material. Placement sites become full more quickly. As a partial fix, the Corps developed a new contract arrangement with private dredging companies to restore placement site capacity through partial offloads of the placement sites. While this action has helped maintain capacity, it also reflects the increased complexity and urgency of routine activities that have been part of the 9' navigation channel maintenance since its inception in the 1930s-40s.

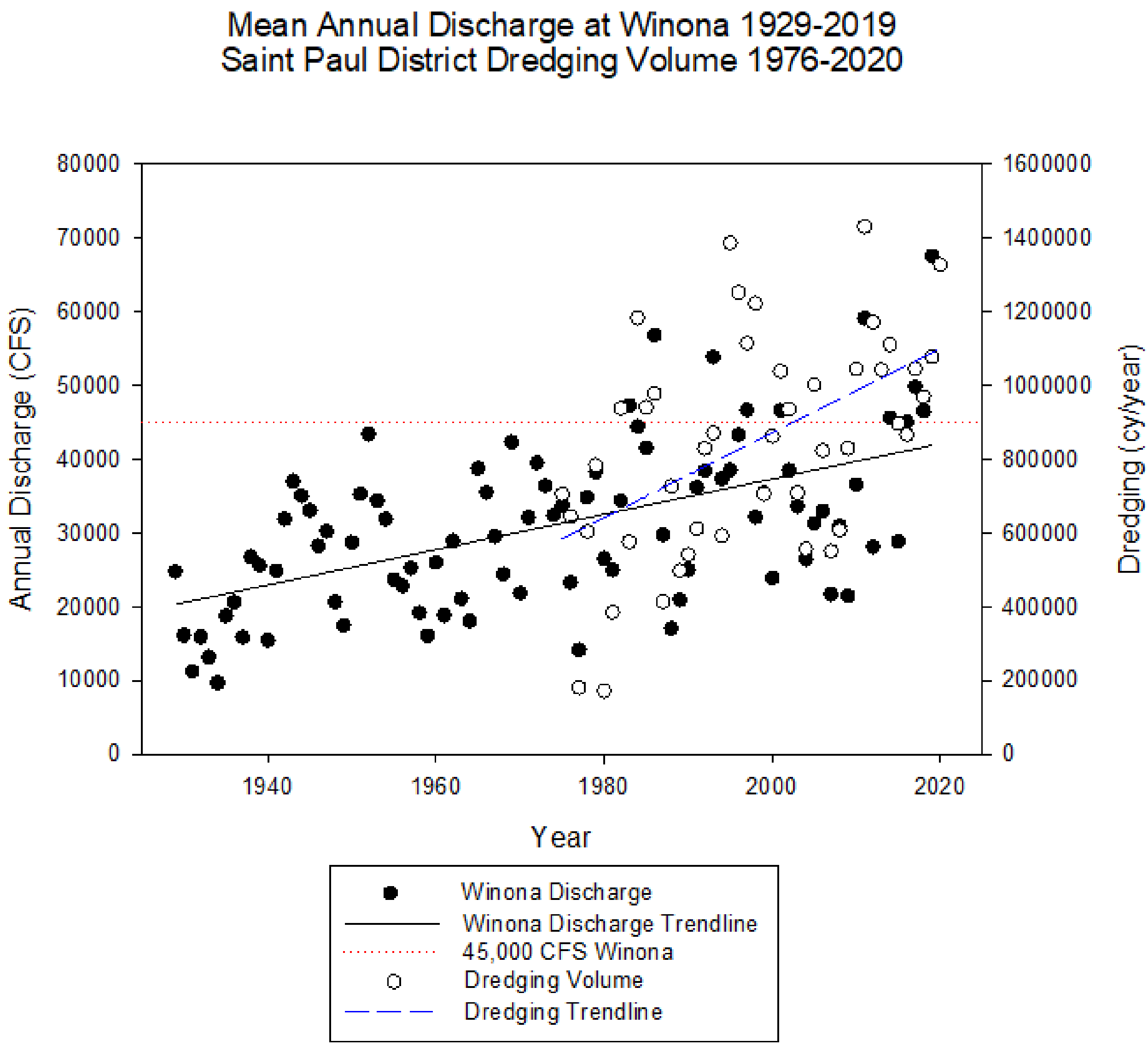


Figure 8. Mean annual discharge at Winona, MN 1929-2019. Saint Paul District navigation channel dredging volume (in cubic yards per year) 1976-2020. Equipment and budget availability can also affect dredging volume in any given year, but the trend for dredging is clearly increasing.

In Pool 6, the recent shift in dredging is notable. Taking 5-year averages starting in 1975 (to reduce year-to-year variability in budgets and equipment), Pool 6 ranked last or near last in volume dredged for every 5-year interval through 2014, typically accounting for approximately 2-4% of the District-wide dredging volume. For the 2015-2019 interval, it jumped to 6th in rank and accounted for 5-11% of the District-wide total (Figure 9). These increased dredging volumes were not part of the long-term strategy for dredged material management in this pool, making placement site capacity dire. As the hydrologic baseline shifts on the River, long-term plans can no longer rely on historic dredging patterns alone to anticipate the future volumes. Even as engineers improve their forecasts, there will also need to be adaptations to policies for real estate acquisition to accommodate increased dredging and budgeting to help ensure that agencies are able to shift operations to the new hydrologic conditions.

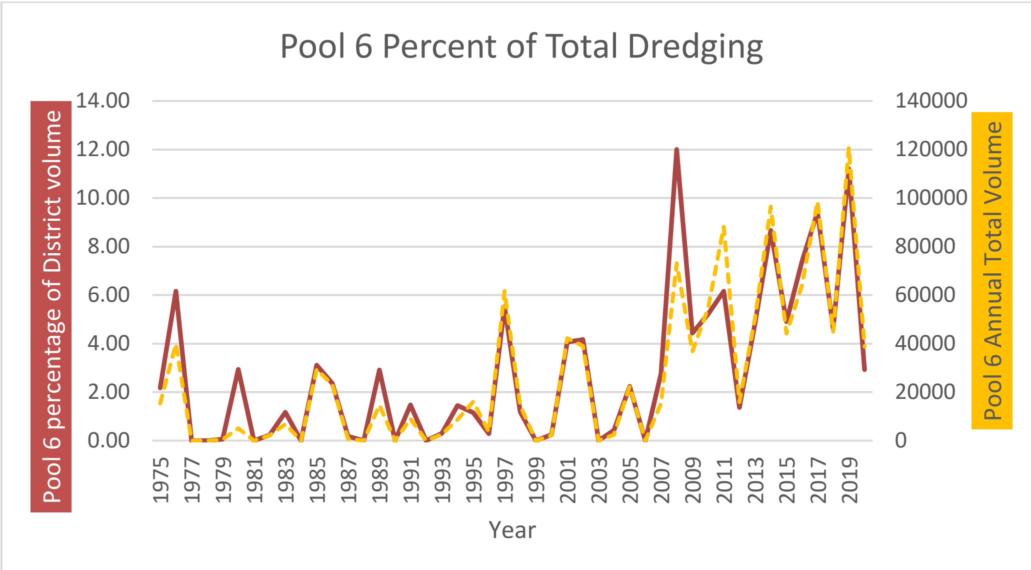


Figure 9. Annual total dredged from Pool 6 in yellow and percentage of the District total in red.

The Upper Mississippi River is also a national commerce highway, designated as a Marine Highway in 2015 and estimated to move 557 million short tons in 2018 in the stretch from Minneapolis to St. Louis, MO. Wisconsin's Mississippi River port in La Crosse received or shipped a total of 201,600 short tons that same year. The allure of marine shipping is to utilize water navigation for bulk commodities and large equipment. This reduces truck and rail traffic and has been identified as a desirable component of regional transportation plans. Moving commerce onto and off marine highways requires investments in ports and transloading facilities strategically placed to match commodity flows and complement existing networks. If marine commerce on the Mississippi River is desirable, it will be necessary to plan and build around the variabilities of climate change. The current marine network has these climate-related vulnerabilities in the present condition:

- Lock closures due to flooding (primarily in Iowa, Illinois & Missouri)
- Impassable natural barriers due to drought
- Delays due to increasing needs to clear sediment from navigation channels

Recognition of these vulnerabilities to commercial navigation was one impetus for a Planning Assistance to States report that was scoped and conducted over the past 5 years among the state and federal agencies through the Upper Mississippi River Basin Association. The forthcoming Keys to the River report offers some near-term recommendations for addressing these threats and outlines numerous areas of research that are necessary to informing decisions and planning in our new climate era. Some areas for further research may include:

- The role of long-distance shipping in regional and national economies
- Potential shifts in agricultural practices in response to a changed regional climate that may require different transportation needs than historic production
- Transportation optimization to address climate change vulnerabilities across competing modalities (i.e. highway flooding versus lock closures versus railroad washouts)
- How should and can the floodplain be altered to allow for effective conveyance of floods and deposition of sediment?

Effect of Climate Change on Backwater Habitat Quality

The breadth of habitat ranging from flowing channels to backwater lakes in floodplain rivers is essential for high biological diversity and ecosystem productivity. Backwater lakes of the Mississippi River are central to the biological productivity and diversity observed within the system. These habitats are critical for backwater dependent organisms both as refugia from high water velocity and as spawning areas. Backwaters are essential for fish nursery habitat, fish overwintering habitat, sediment and nutrient assimilation, aquatic plant production, zooplankton production and waterfowl and wildlife habitat. Unfortunately, the backwaters of the Mississippi have suffered some of the most serious degradation as a result of changing climatic conditions. Even before hydrologic patterns began shifting, backwater systems were impacted by the "over-connection" that occurred when these once partially-isolated habitats became interconnected with the main channel of the River through impoundment of the River to create the navigation pools of the Upper Mississippi River System 9' Navigation Project (UMRS). While the UMRS improves transportation opportunities, it fundamentally increased the level of connection between the main channel and all the other habitats of the river floodplain. As a partnership, the Upper Mississippi River states and federal agencies have conducted habitat restoration projects and modified routine operations to try to reverse some of the degradation that has occurred. Projects that restored land masses to areas where they were lost through erosion, reduced wind resuspension of sediments, redefined relict channels and created sheltered areas for plants and wildlife. The continued shift of hydrologic conditions to a longer duration, higher stage, late-season flood regime has profound impacts on our remaining habitats and creates an urgency to address their fate.

Backwaters of the Mississippi have different degrees of connection to main or side channel water input. Water residence time (flushing rate) of backwaters can range from many months to days depending on the degree of connection to channel flows. This variable degree of connection to channel flows is a critical element of habitat and water quality diversity for the system. In a natural river, habitats can form and change as a result of changes in discharge and sediment and debris loads. In an impounded river, the permanent alterations of water elevation and available energy disrupt the resilience of habitats and result in greater limitations on habitat health due to their narrow operating band.

The backwater type that has suffered the most serious consequences due to climate change are the V-shaped islands out in the main thread of main channel flow (Figure 10). Many of these islands date to post-glaciation river valley development when the river formed a channel network in a bed of sand. They became an important habitat component under the variable flows of the river and have served a valuable niche since the river was impounded and isolated backwater lakes were lost. These backwaters also contribute to the aesthetic beauty of the river valley and operate in a critical water velocity band within the continuum of river habitat conditions. One such island that has suffered negative consequences of climate change is Johnson Island in Trempealeau County (Pool 6). Since 2015, substantial erosion to the island and tree loss has occurred, the volume of water moving through the complex has dramatically increased, depositing large quantities of sand in the backwater that reduced water depth. The combination of a new breach in the natural levee and increased river discharge caused sediment deposition (Figure 10). The large degree of change in just six years is a result of steadily increasing discharge and sustained high river stage. In sum, more water and sediment are pressuring the ecosystem and its unique habitats.

Figure 10. Negative ecosystem consequences observed in the Johnson Island Complex in Trempealeau County since 2015.

The V-shaped islands that operate as flow-through backwaters (have a channel entering near the upstream end) are near the middle of the water residence time range and are therefore critical for habitat and biological diversity. One backwater that has changed dramatically as result of climate change is Probst Lake in Pool 5 near Alma, WI (Figure 11). Inflow to this backwater increased substantially over the past decade, and discharge in Pool 5 has shifted in timing and magnitude (Figure 12). During 1980-2010, the typical pattern consisted of a spring flood (typically early April) followed by a predictable decline in river discharge into the summer months. During 2011-2019, discharge on any given day was higher and the flood peak occurred later (May-July). During the most recent time period (2011-2019) total inflow into Probst Lake increased and water residence time (number of days to replace water in a backwater) dramatically decreased. This change in the flushing rate of backwaters is upsetting seasonal rhythms on the Mississippi.

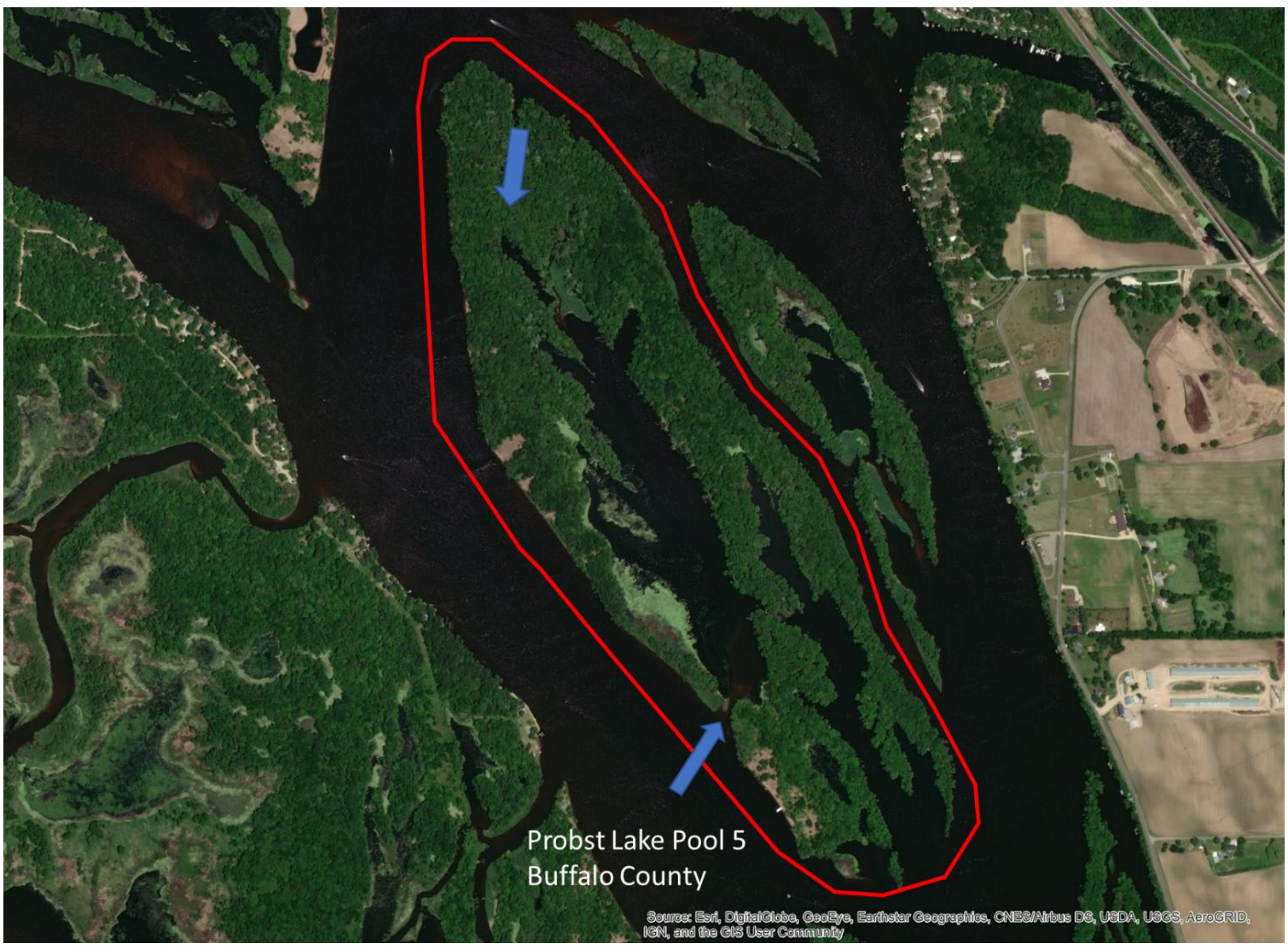


Figure 11. Probst Lake in Pool 5 near Alma, WI. Channel water enters Probst Lake through two inlets.

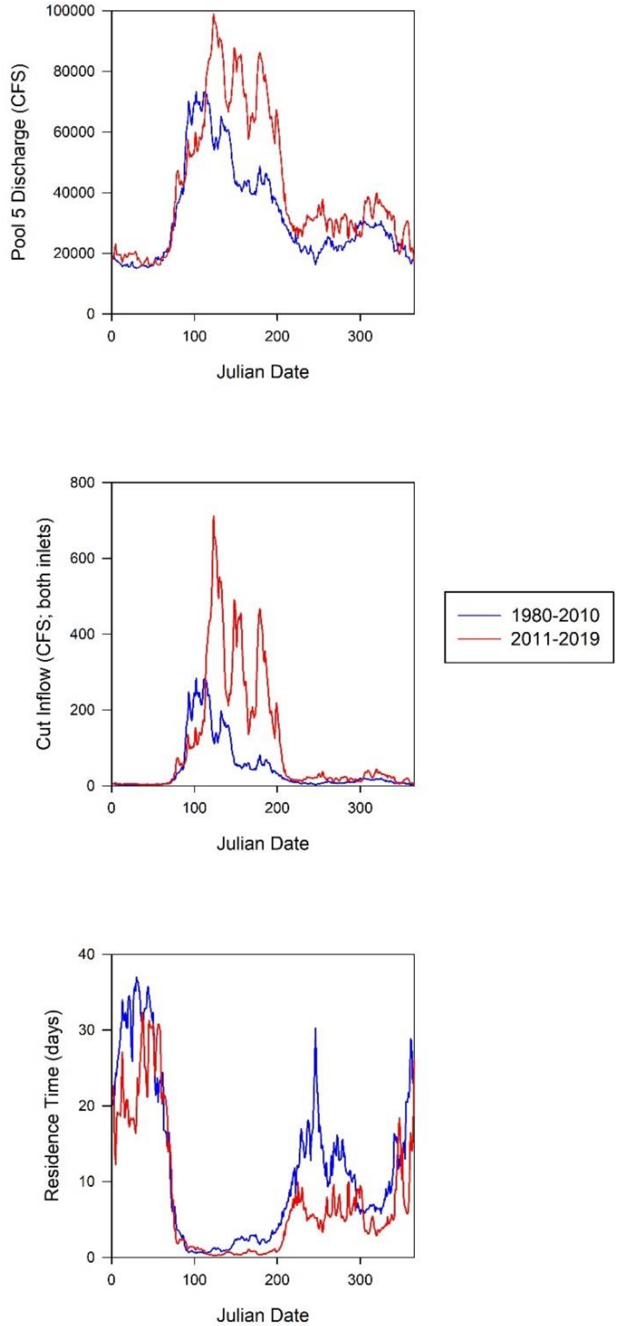


Figure 12. Pool 5 median discharge (upper panel), median inflow to Probst Lake (middle panel), and median water residence time in Probst Lake (bottom panel) by Julian date (January 1=day 1; December 31= day 365). CFS = cubic feet per second.

Changing Winter Water Quality and Habitat Dynamics

How large changes in backwater flushing rates are affecting the ecosystem is only beginning to be fully understood. However, evidence is building that indicates primary productivity, zooplankton production and fisheries recruitment may be jeopardized by climate-driven increases in discharge. One mechanism that is well understood and is experiencing negative change is fisheries overwintering in habitats like Probst Lake. Many floodplain river organisms are dependent on quiescent habitat as refugia from high water velocity. Backwater fish species, such as bluegill, are particularly dependent on low velocity water during the winter months. In the winter months, water temperature in channel environments is very cold and typically near 0° C, but typically with high dissolved oxygen (0.1° C and 12 mg/L dissolved oxygen are common January values). Many backwater dependent species cannot tolerate winter temperatures near 0° C for extended periods of time, but like all aquatic life require sufficient dissolved oxygen. Winter requirements for backwater fish species include water that is sufficiently warm (> 1° C), but with adequate dissolved oxygen (> 3 mg/L). For flow-through backwaters like Probst Lake, a narrow band during the winter months exists for backwater fish survival. Too much cold water entering from the main channel makes the backwaters too cold. Yet, not enough main-channel input results in too little dissolved oxygen in the backwaters. Between these two extremes, the correct amount of main-channel input creates the ideal mix of temperature and oxygen, sometimes referred to as the “Goldilocks Zone” (Figure 13). As a result of this narrow environmental requirement band, a small percentage of total river area is suitable as overwintering habitat (typically < 5% of total area). Because dams and navigation infrastructure control the system response, and constrain the creation of new backwaters, we see a slow decline in these critical habitats without a natural recovery process that can adapt to changes in discharge.

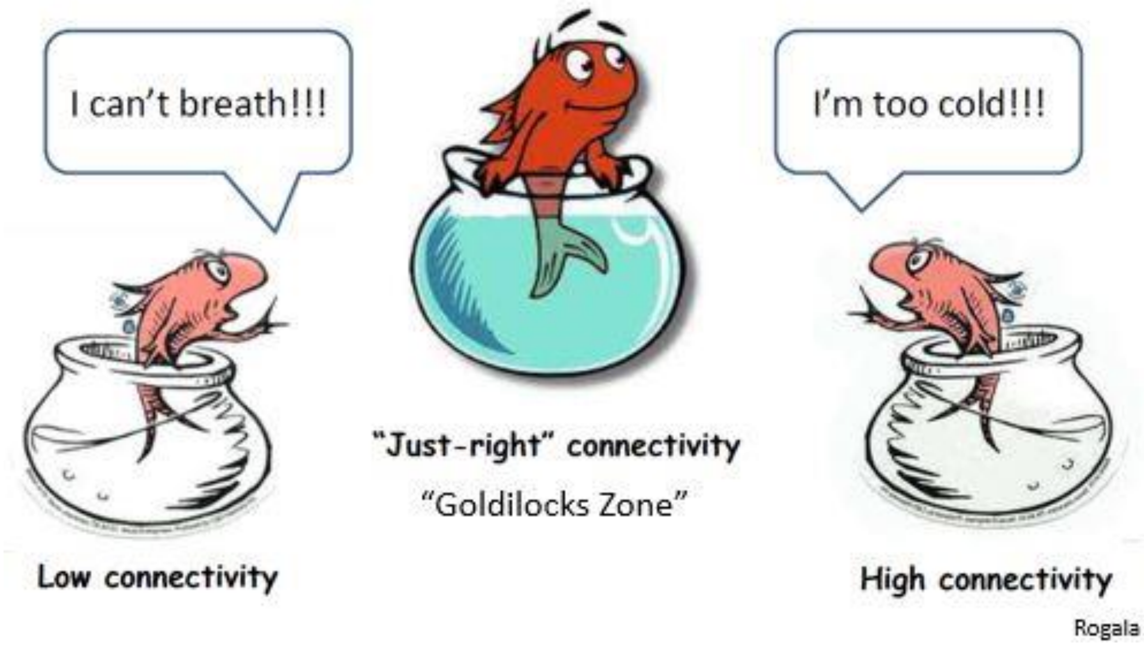


Figure 13. Depiction of the narrow band of temperature and dissolved oxygen required by backwater fishes during winter. Cartoon Credit: James Rogala.

Many backwater lakes no longer operate within the "Goldilocks Zone" and are not functioning as productive overwintering fish habitat. Probst Lake is an example of a backwater that has lost much of its overwintering refugia function during the high discharge era. Recent data collected using continuous temperature and dissolved oxygen data (measurements every 15 minutes) describes this loss of ecosystem function. Prior studies to estimate optimal water residence time to produce adequate water temperatures (> 1° C) and dissolved oxygen (> 3 mg/L) determined that a water residence time of roughly 12 days generally provides productive backwater overwintering habitat. Continuous temperature and dissolved oxygen data collected during a recent high discharge winter when Probst Lake was flushing very fast (~2 days residence time) revealed inadequate conditions (Figure 14). While dissolved oxygen was more than adequate (~ 12-13 mg/L), large input of cold channel water resulted in water temperature well below the required 1° C (~0.1-0.2° C). Probst Lake is just one example of this widespread phenomenon among Mississippi backwaters during the high discharge era.

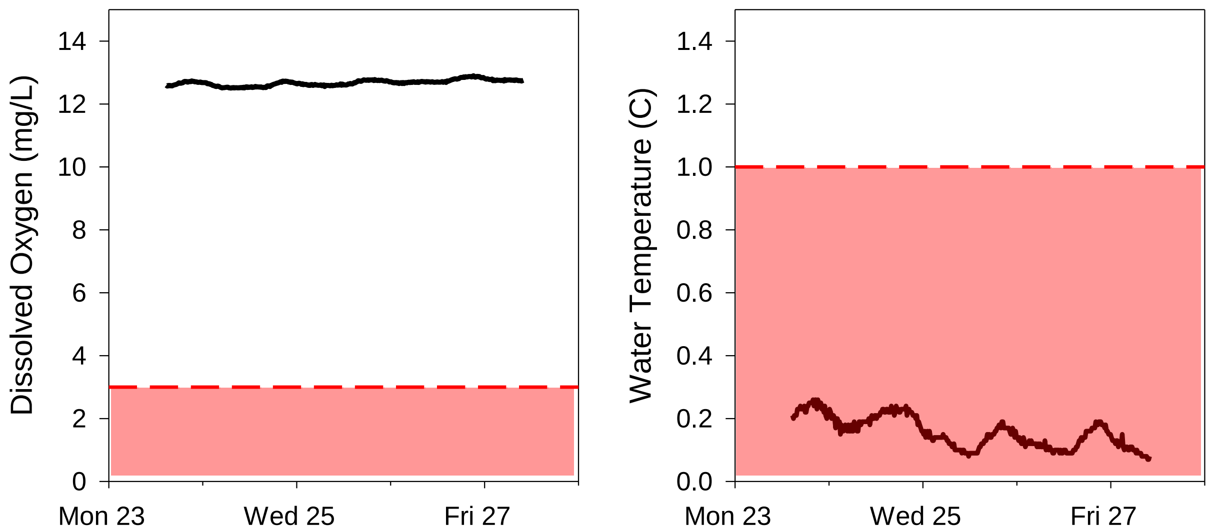


Figure 14. Dissolved oxygen and water temperature collected using continuous meters deployed under the ice in Probst Lake during a recent high discharge winter. Cold water temperature observed (< 1° C) was more indicative of a flowing channel condition than backwater condition during the winter months. The pink shading represents the poor winter habitat quality range.

Coincident with increasing discharge, backwater environments on the Mississippi River have lost water depth over time (typical sedimentation rate of ~0.5 cm/year) due to the navigation dams limiting the ability of backwaters to flush sediment. Over a timespan of decades, the typical Mississippi River backwater has become shallower. Additionally, deep backwaters are filling at a faster rate than shallow backwaters. Deep backwater areas (> 6.5 feet) are important overwintering fisheries habitats that allow cold, less dense water to flow over the top of water with sufficient water temperature and oxygen at depth (Figure 15). Data collected from Johnson Island near Trempealeau, WI during a recent high discharge winter illustrates the deep-water winter refugia dynamic. In the upstream end of the complex (water depth < 6 feet) water temperatures were too cold top to bottom (near 0° C). Conversely, in the downstream end of the complex, where deeper water still exists, a zone between 6.6-9.8 feet water depth produces the optimal mix of water that is sufficiently warm with adequate dissolved oxygen (Figure 16). This type of deep backwater is becoming increasingly scarce and reestablishing adequate backwater depth in strategic locations is acknowledged as an important benchmark to promote ecosystem resilience during the climate change era.

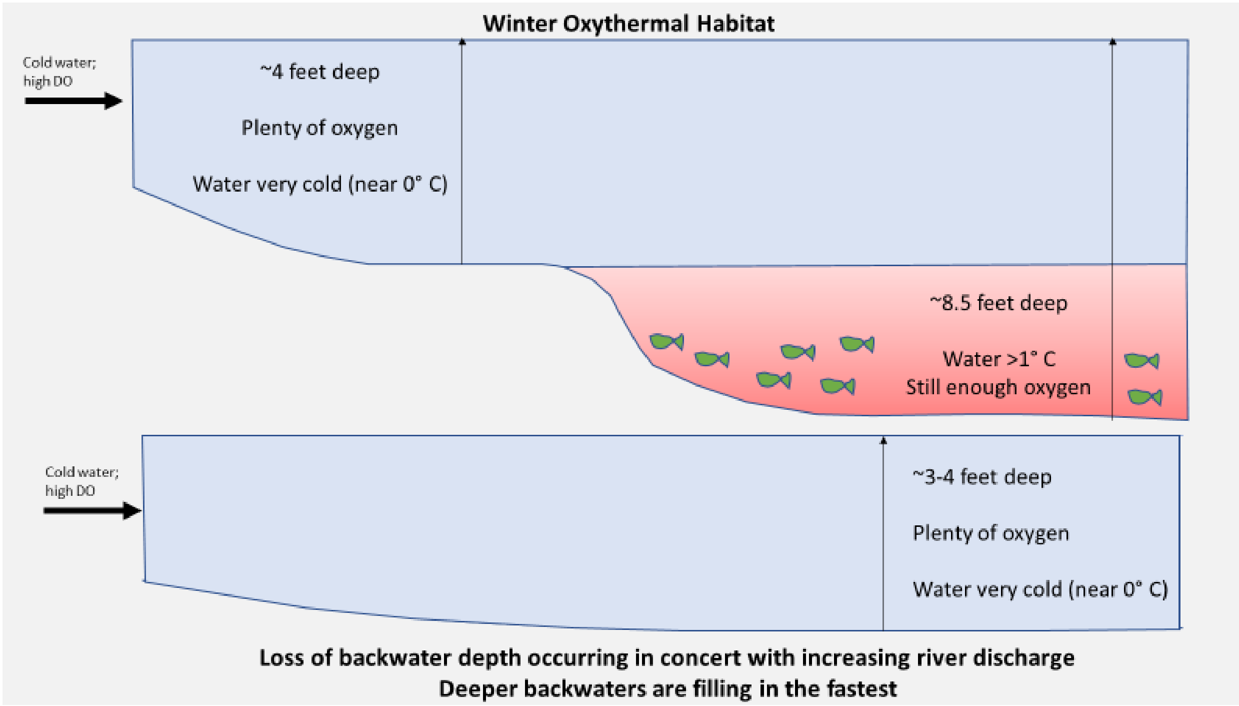


Figure 15. The bottom panel depicts a typical modern, shallow backwater exhibiting cold water top to bottom. The top panel depicts an idealized backwater profile with adequate depth to produce thermal refugia near the bottom despite high discharge during the winter months.

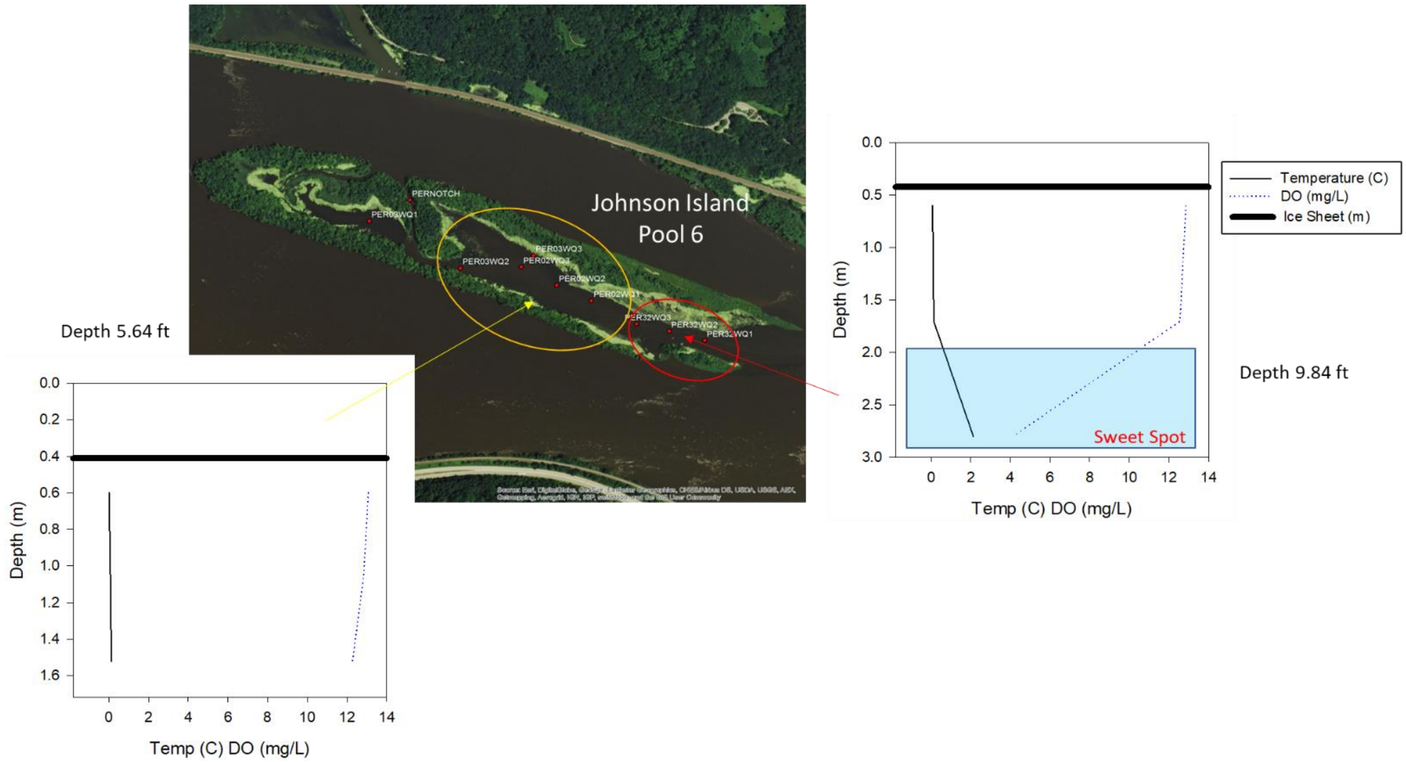


Figure 16. Temperature and dissolved oxygen profiles in shallow (< 6 feet) and deep (> 9 feet) zones of Johnson Island during a high discharge winter. The deep sampling site exhibits a favorable mix of warm water with adequate oxygen during the winter months.

Unforeseen Climate Consequences

The climate change era has resulted in negative ecosystem consequences that would have been difficult to foresee several decades prior. One example of an area negatively impacted by unforeseen climate impacts is the Trempealeau National Wildlife Refuge near Trempealeau, WI (Figure 17). This refuge is unique in that it is effectively leveed off from the Mississippi River by the railroad grade on the Wisconsin bank. A habitat project in the early 1990s at the refuge was designed to implement water drawdowns to promote high quality food resources for migrating waterfowl. During the past decade, high river stages on both the Trempealeau and Mississippi Rivers prevented refuge staff from implementing the prescribed water drawdowns due to water elevation outside the isolated refuge being higher than those inside the refuge. Inability to conduct water drawdowns resulted in a shift to a turbid, unvegetated ecological state dominated by cyanobacteria and lacking rooted aquatic vegetation (Figure 17). During the recent period without drawdowns, phosphorus within the refuge has continued to build up. The combination of high phosphorus, warm water temperatures, shallow water depth, and lack of any flushing due to being isolated from the Mississippi River have resulted in severe nuisance bloom conditions (chlorophyll a >60 µg/L) about 65 percent of the time during the growing season (Figure 18). The phytoplankton community within the refuge is dominated by cyanobacteria (Figure 19). During a 2019 study of eight backwater lakes, water within the refuge was the most elevated for the cyanotoxins microcystin and anatoxin-a. Microcystin is a potent liver toxin and anatoxin-a is a potent neurotoxin. Based on unforeseen climate consequences, adaptive actions within the refuge will be required to restore it to a healthy ecological state.

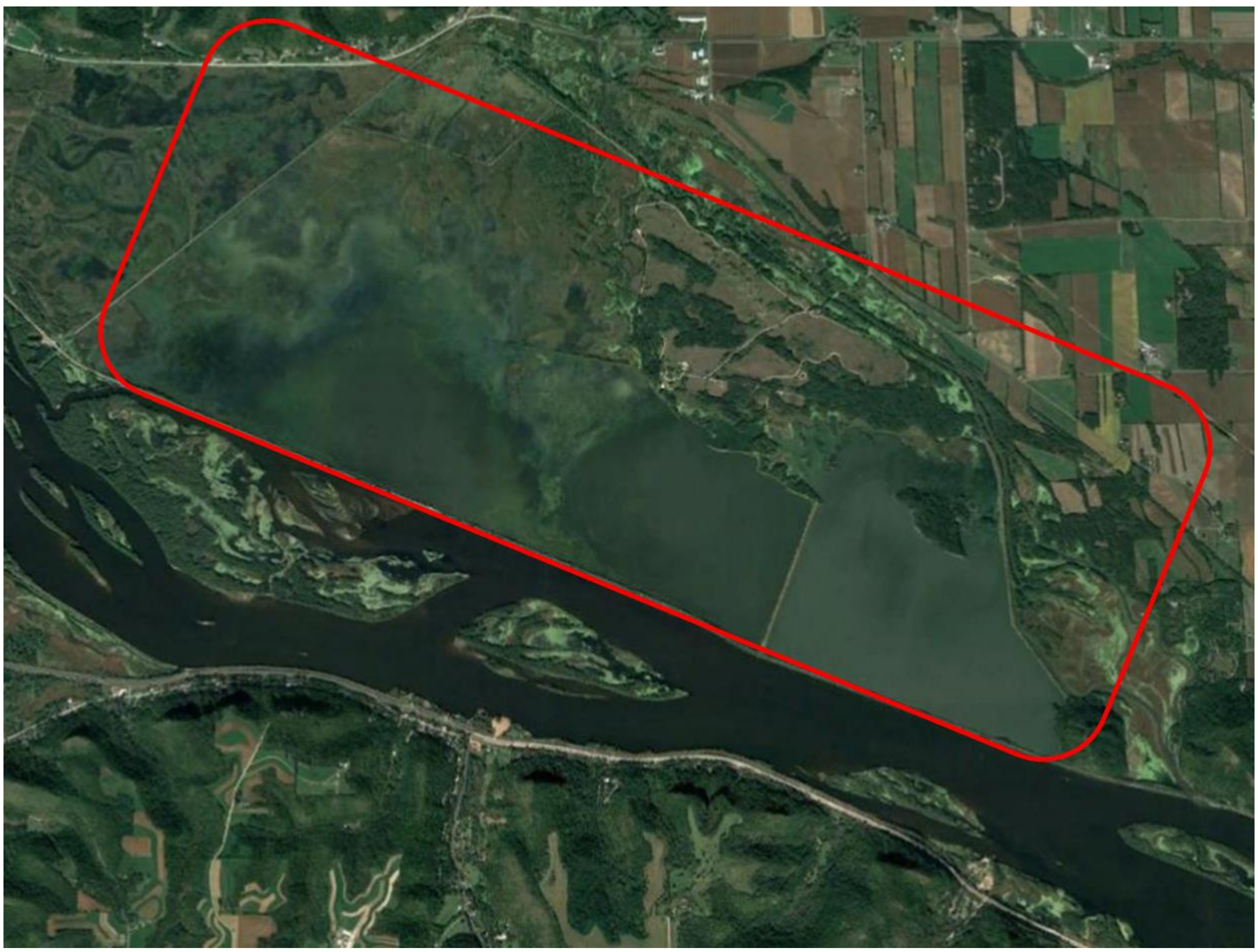


Figure 17. Area inside the red rectangle is the Trempealeau National Wildlife Refuge. The opaque water visible via aerial imagery is an indicator of a major phytoplankton bloom. The difference between the water in Pool 6 to the south compared with the refuge is evident (indicative of clear vs. turbid ecological states).

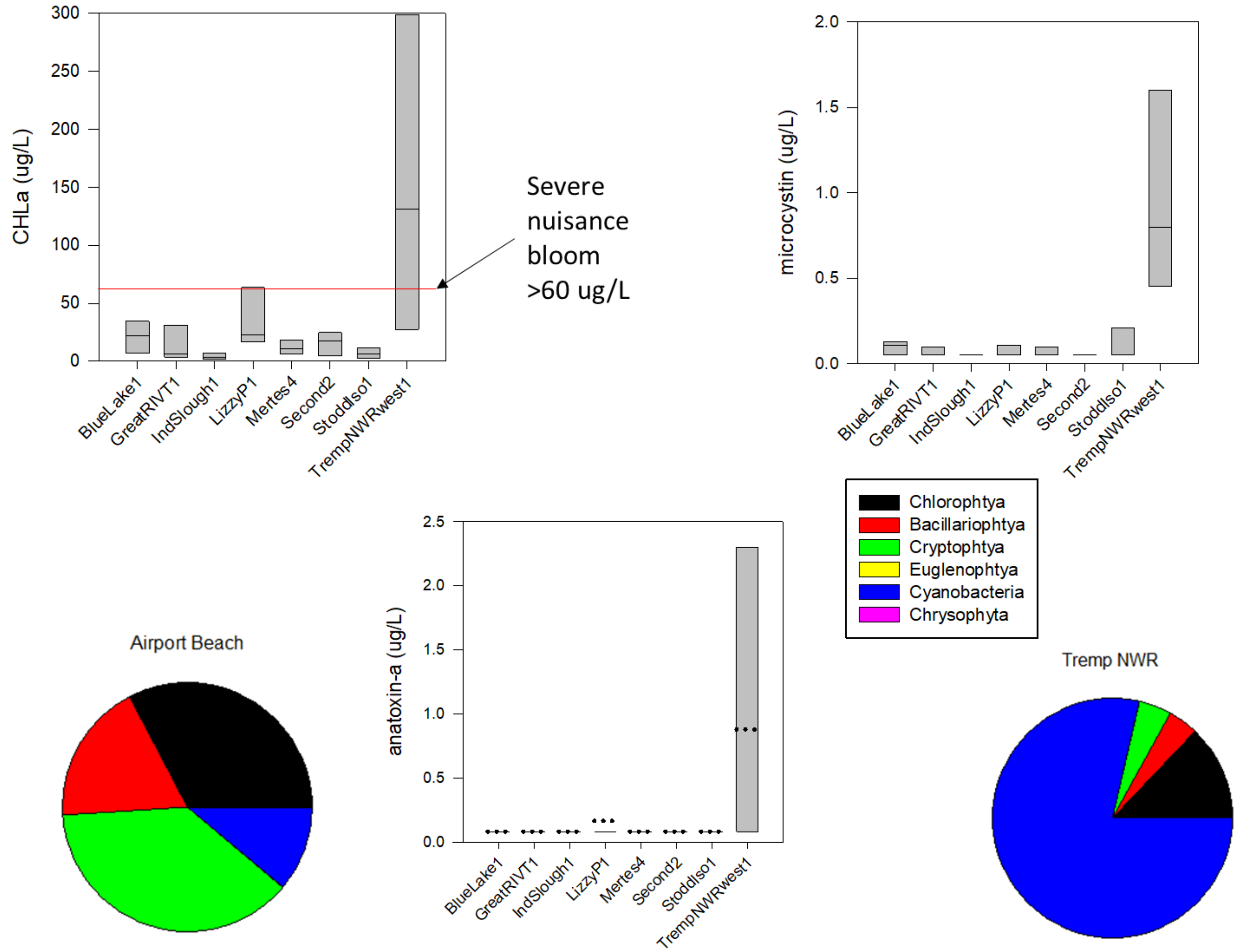


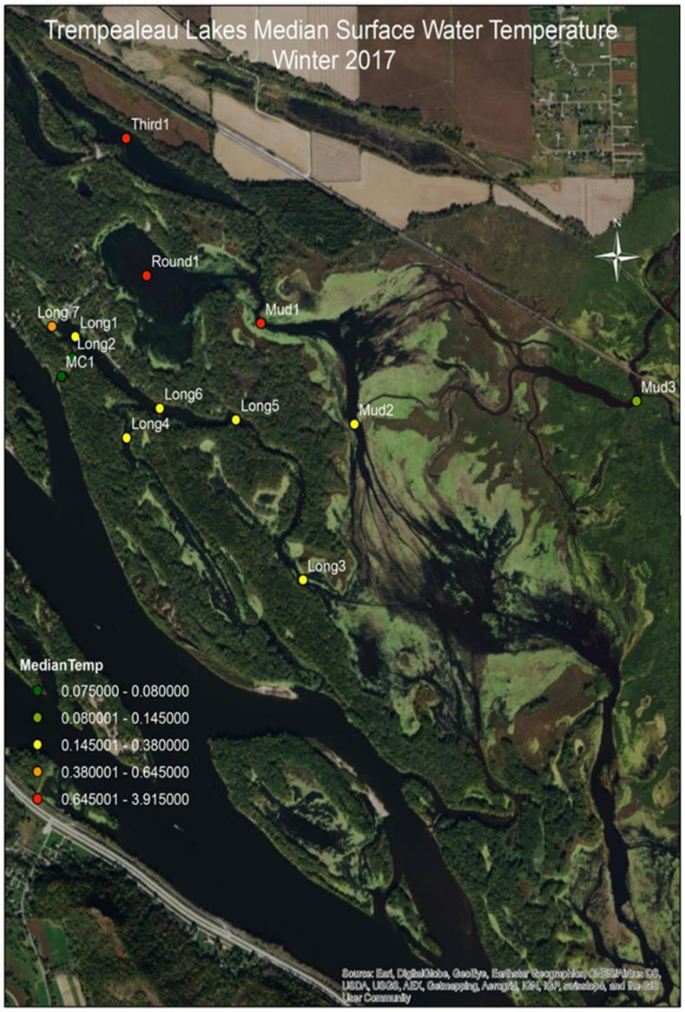
Figure 18. Chlorophyll *a* (an indicator of phytoplankton biomass), microcystin and anatoxin-a data from eight Mississippi River backwaters during the growing season of 2019. The Trempealeau Wildlife Refuge data is the furthest right on each panel. The boxplot ends represent the 25th and 75th percentiles. The solid line within the boxplots is the median. The dotted lines represent the mean. The pie charts represent the proportion of the phytoplankton community comprised of cyanobacteria and other taxa within the refuge compared with a more typical Mississippi River site from a 2017 survey.

Figure 19. A summer cyanobacteria bloom within the Trempealeau National Wildlife Refuge.

Adapting to Climate Change

While the challenges related to climate change are substantial, it is encouraging to note that applied science approaches to adapt to a changing climate are being implemented on the Mississippi River with success. Floodplain rivers like the Mississippi have tremendous capacity to heal themselves if adaptive measures can be employed to restore realistic ecosystem conditions that preceded the recent era of degradation. Long Lake in Trempealeau County is one example where applied science adaptations have enhanced ecosystem resilience. A comprehensive water quality survey of the Trempealeau Lakes was conducted in 2016-2017.

These lakes are regionally important as a recreational resource due to the relative paucity of lakes in the unglaciated Driftless region. The water quality survey revealed conditions within Long Lake during the winter months that were insufficient as winter fisheries habitat due to a large influx of cold main channel water into the complex during recent high discharge winters (Figure 20). Settings at the water control structure that were formerly effective were no longer producing optimal winter water quality in the climate change era. Elevated winter flows into Long Lake coupled with high variability in winter river stage during the recent era were resulting in poor winter water quality. The solution was a unique management plan employed at the water control structure entering Long Lake. A slot in one of the stoplogs was cut to convey the ideal flow rate into Long Lake (two cubic feet per second) in order to achieve the optimal mix of warm water temperatures and adequate dissolved oxygen. This slotted stoplog was placed at depth, below the depth of a typical ice sheet thickness. Additional stoplogs were placed above the slotted stoplog to an elevation higher than would be observed during even the highest of winter river stages. The new management operation resulted in a substantial improvement in winter water quality and an enhancement in recreational ice fishing opportunities (Figure 21). A summer setting was also established to achieve optimal dissolved oxygen and nitrogen assimilation during the summer months. High quality water quality conditions are now being achieved with just two annual board adjustment at the water control structure.



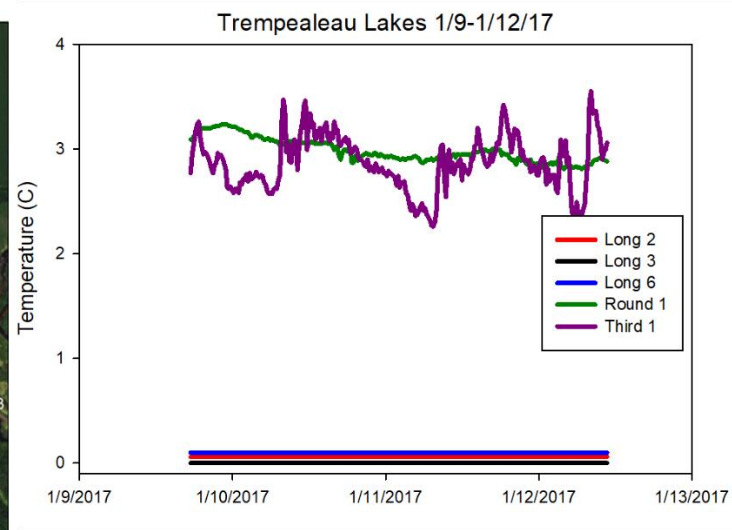


Figure 20. The panel on left is depicting median water temperatures (in ° C; 0.66 feet below the ice) within the Trempealeau Lakes during the winter of 2017. The panel on the right is continuous water temperature data collected via continuous sensors (picture below) placed 1.5 feet below the ice during January of 2017 at Long Lake, Round Lake and Third Lakes. Note the winter water temperature values at all Long Lake sites well below 1° C.

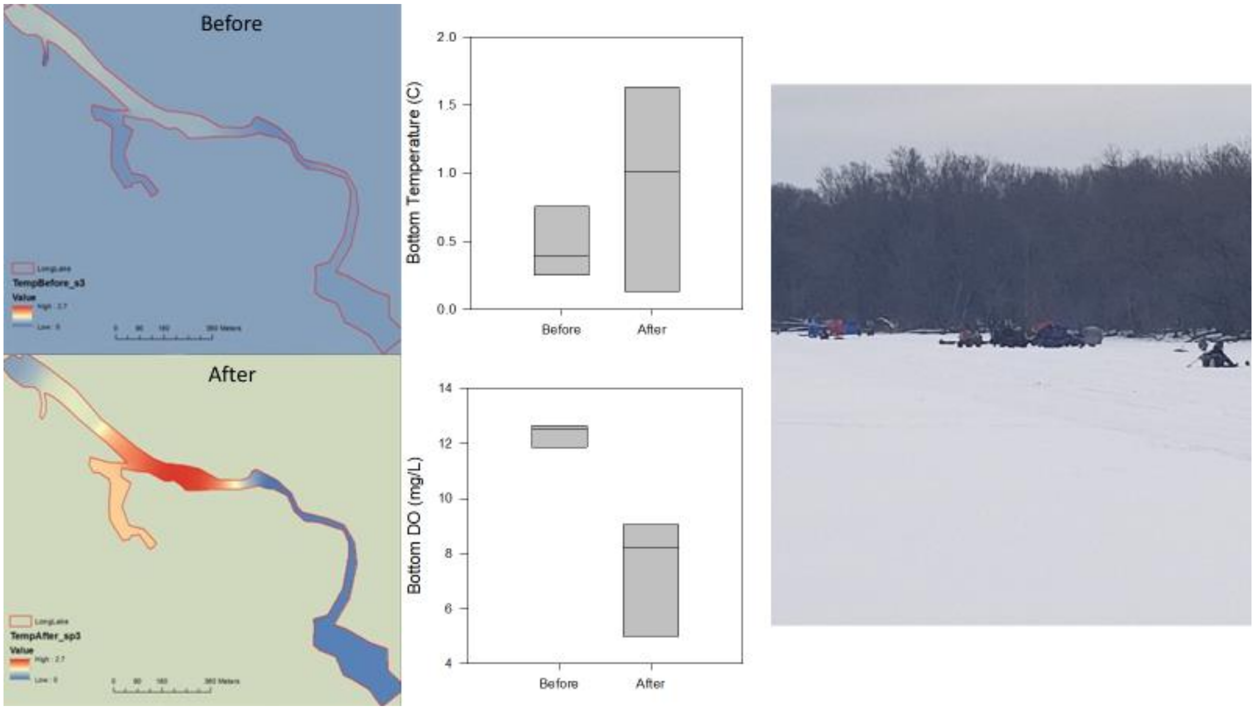


Figure 21. Water temperature and dissolved oxygen data within Long Lake before and after implementing the slotted stoplog adaptive management method. The heat maps on the left are water temperature (0.66 feet off the bottom) before and after management action. The boxplots present bottom temperature and dissolved oxygen before and after management action. The photo on the right shows high use of Long Lake for recreational ice fishing following the management change, an activity that had been nearly non-existent in recent years due to the changes in flow.

Infrastructure retrofits are another approach to adapt to changing climatic conditions and are exemplified on Wing Lake in La Crosse County. One such retrofit occurred during a construction project in La Crosse County. The water in Wing Lake was conveyed under County Highway GI through uncontrolled culverts for many years. The culverts were resulting in water quality problems. Under low river stage, the culverts would perch (conveying no flow through Wing Lake) and low oxygen conditions would rapidly develop. Under high discharge winters, high volume of cold, channel water was conveyed through Wing Lake resulting in water too cold for overwintering organisms. The solution was to replace the uncontrolled culverts with a water control structure that would regulate winter flow rates while still allowing for increased flood conveyance. This was achieved by designing a control structure with stoplogs that would allow for flow control during even very high winter discharge (Figure 22). This system is now being managed with the slotted stoplog method which has improved water quality during multiple seasons with minimal stoplog modifications (Figures 23-24). Solutions such as this require incorporating the input and expertise of biologists, hydrologists and water quality experts to develop optimal conditions for natural resources that are altered by infrastructure. As climate drives an increase in storm intensity and frequency, there will continue to be infrastructure damages that offer opportunities for upgrading infrastructure to be more resilient to future conditions. Ensuring good communications between the grey and the green infrastructure experts will optimize investments.

Figure 22. Photo on left shows uncontrolled culverts. Photo on right shows the climate adaptation design with water control via stoplogs up to river elevation of 632 feet. At water surface elevation greater than 632 feet, water is uncontrolled.

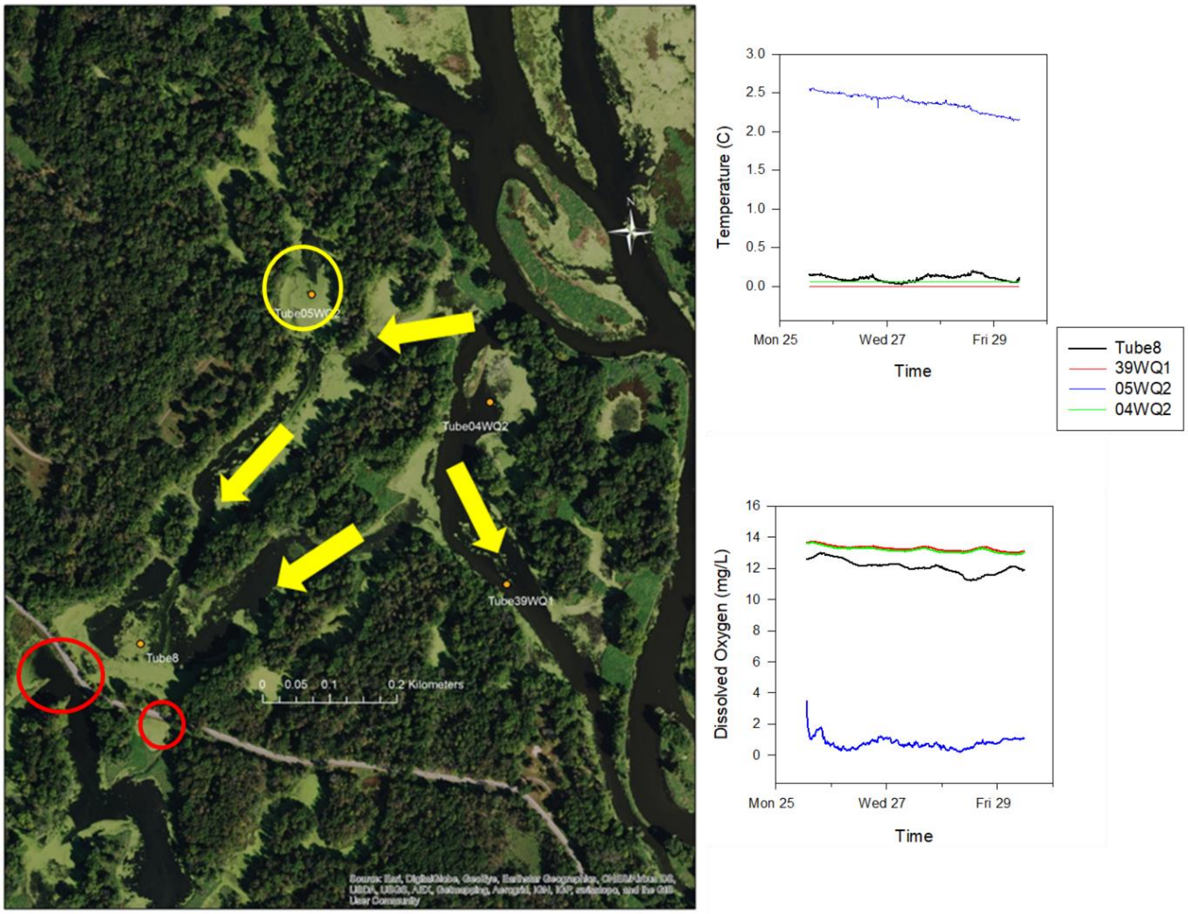


Figure 23. Continuous water temperature and dissolved oxygen in Wing Lake during elevated winter discharge. The flow vectors are depicted with yellow arrows. The formerly uncontrolled culverts lie within the red circles. Three of the four sites sampled that were in high water velocity conditions exhibited very cold water (< 1° C). The site out of high-water velocity (05WQ2; in the yellow circle) exhibited sufficiently warm water (> 1° C) but hypoxic conditions (dissolved oxygen < 2 mg/L). This resulted in a lack of suitable winter habitat throughout Wing Lake that merited management action.

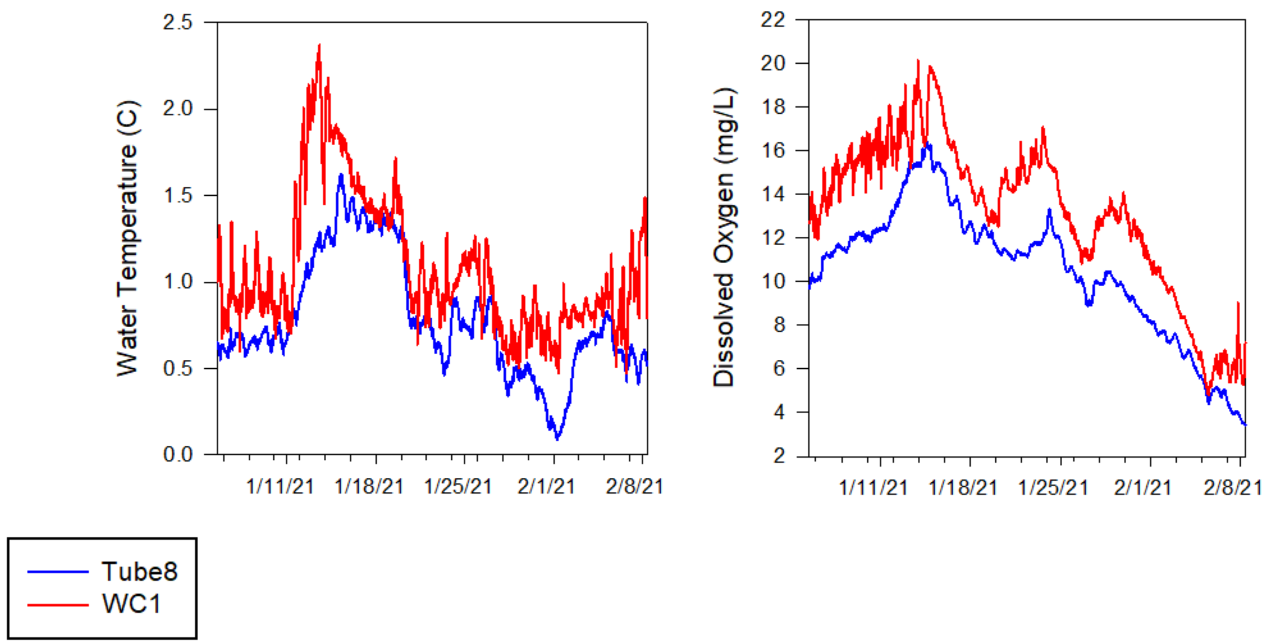


Figure 24. Continuous water temperature and dissolved oxygen in Wing Lake following management action. Warmer water temperature was produced while maintaining sufficient dissolved oxygen for overwintering fish. Site WC1 is located within the furthest left red circle on Figure 23 and represents water leaving Wing Lake.

The Mississippi River has a rich history of community engagement, advocacy and stewardship of its recreational and ecological assets. One community-led, low-cost climate adaptation example occurred in Blackdeer Channel in Lake Onalaska. A floodplain island breach upstream of a critical fish overwintering area opened up during recent high discharge years (Figure 25). Water quality and fish habitat declined with the influx of cold, low oxygen water into the complex. WI DNR coordinated with the Fish and Wildlife Service and the Brice Prairie Conservation Association to improve winter habitat conditions. A local project to control invasive buckthorn was utilized to implement a solution. The invasive buckthorn was cut and constructed into brush bundles, which were staked in the breach opening to limit the influx of cold, low oxygen water into the overwintering site (Figure 26). Post-project monitoring documented warmer water with adequate dissolved oxygen during the winter months. Further refinements are planned for 2021 and beyond. This project represents a creative ecosystem improvement solution that provides dual benefits for invasive species control and aquatic water quality improvement that was implemented at very low-cost utilizing citizen leadership for project implementation.

Figure 25. Location of the Blackdeer Channel levee breach upstream of a critical overwintering area in Lake Onalaska.

Figure 26. Top panel: Levee breach prior to buckthorn bundling project. Bottom panel: Post-project breach reduction using the buckthorn brush bundling technique.

The threats to the Mississippi River ecosystem as a result of climate induced changes are substantial. While many stressors resulting from climate change are well described, many more are not yet fully understood. As society moves toward implementation of solutions that will require global cooperation, it is important to recognize and implement near-term, local adaptive measure to lessen the ecosystem shocks that are likely to come. We have shared some examples of these challenges and successful adaptive measures on the Mississippi River. River systems can be recovered if we minimize encroachments and restore physical and biological processes that have been interrupted or altered. The future challenge will be to implement adaptive measures at the scope and scale required to maintain a viable Mississippi River ecosystem for future generations.